東北地方の落雷位置標定システムを用いた寒候期雷活動の時空間構造に関する研究

著者	鶴島 大樹
学位授与機関	Tohoku University
学位授与番号	環博第83号
URL	http://hdl.handle.net/10097/58204

	つるしま　だいき
氏　　　　　名	鶴島　大樹
授　与　学　位	博士（環境科学）
学 位 記 番 号	
学位授与年月日	平成 26 年 3 月 26 日
学位授与の根拠法規	学位規則第 4 条第 1 項
研究科，専攻の名称	東北大学大学院環境科学研究科（博士課程）環境科学専攻
学 位 論 文 題 目	東北地方の落雷位置標定システムを用いた寒候期雷活動の時空間構造に関する研究
指　導　教　員	東北大学教授　境田　清隆
論 文 審 査 委 員	主査　東北大学教授　境田　清隆　東北大学准教授　上田　元 東北大学准教授　村田　功

論 文 内 容 要 旨

1. Introduction

Coastal area of the Sea of Japan is one of the well-known hotspots of winter lightning activity in the world (Racov and Uman, 2007). Since winter lightning contains more electrically intensive discharge than summer lightning (e.g. Brook et al., 1982), winter lightning often causes serious damage on electrical equipments (Transmission lines, wind turbines etc.).

In Japan, district-wide lightning detection networks have been established since the 1980s. These networks are generally called Lightning Location System (LLS) and able to measure lightning stroke locations and their time of occurrence with extremely high accuracy. With the aid of LLS observations, numerous studies have been conducted to clarify spatial and temporal variations of winter lightning activity in the coastal areas of the Sea of Japan (e.g. Fujisawa and Kawamura, 2005). However, there are few studies concerning the meteorological background that determines the characteristics of winter lightning activity in these regions.

Therefore, the aim of this study is to clarify the features of meteorological fields associated with lightning activity during the cold season (Oct-Mar), based on 17-years of observational data collected by LLS in Tohoku district.

2. Data and methods

2.1. Overview of the LLS in Tohoku district

The LLS in Tohoku district, which consists of 9 IMPACT sensors distributed in Tohoku district (Fig.1), was operated by Tohoku Electric Power Company since 1994 to 2010. These sensors are able to detect electromagnetic pulses emitted from lightning discharge to estimate lightning stroke locations within the area containing Tohoku, Hokuriku and northern part of Kanto districts. The lightning location accuracy of the LLS is approximately 2km and lightning detection efficiency is evaluated as 60% or more (Honma et al., 1998; Honma, 2010).

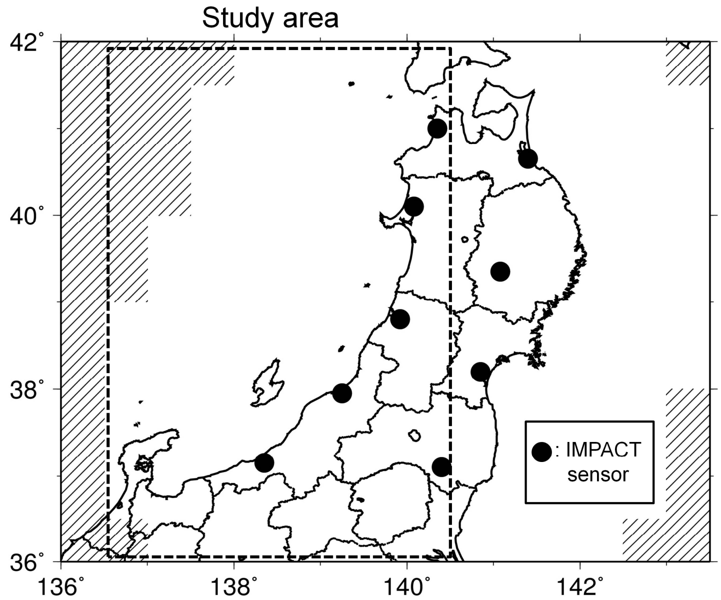

Fig.1 Location of the IMPACT sensors in Tohoku district. Meshed area indicates undetected zones of lightning discharge with absolute peak currents below 10kA.

2.2. Data

This study is based on the analysis of “lightning location data” collected by LLS in Tohoku district. The lightning location data records the lightning stroke location (Longitude, Latitude), time of occurrence (micro-second) and peak electric current intensity (kA).

Additionally, gridded meteorological data (ERA-interim and MSM-GPV) is also analyzed in this study so as to examine relationships between lightning activity and the synoptic-scale meteorological background. The ERA-interim reanalysis data, covering the period from 1979 onwards, provides synoptic-scale meteorological fields with a 70km x 70km horizontal resolution. On the other hand, the MSM-GPV provides more detailed meteorological fields than ERA-interim (10km x 10km horizontal resolution), but covers only a limited time period (2006 onwards).

3. Results and concluding remarks

3.1. Statistical features of cold-season lightning activity

Annual mean lightning frequency distributions in Tohoku district are estimated and shown in Fig.2. In Fig.2 the lightning frequency on each grid cell is expressed as percentage of lightning stroke counts to total lightning frequency in the whole study area (total lightning frequency is expressed in the bottom-right corner of each map).

During late-autumn season (Oct-Nov), lightning frequency is the highest and lightning activity is the most intensive in the ocean and coastal areas of Tohoku district. During mid-winter season

(Dec-Jan), the region of intense lightning activity moves southward to Hokuriku district, where most of the lightning strokes tend to concentrate near the coastlines. Late-winter season (Feb-Mar) that displays the lowest lightning frequency, see the region of intense lightning activity move slightly northward to Tohoku district.

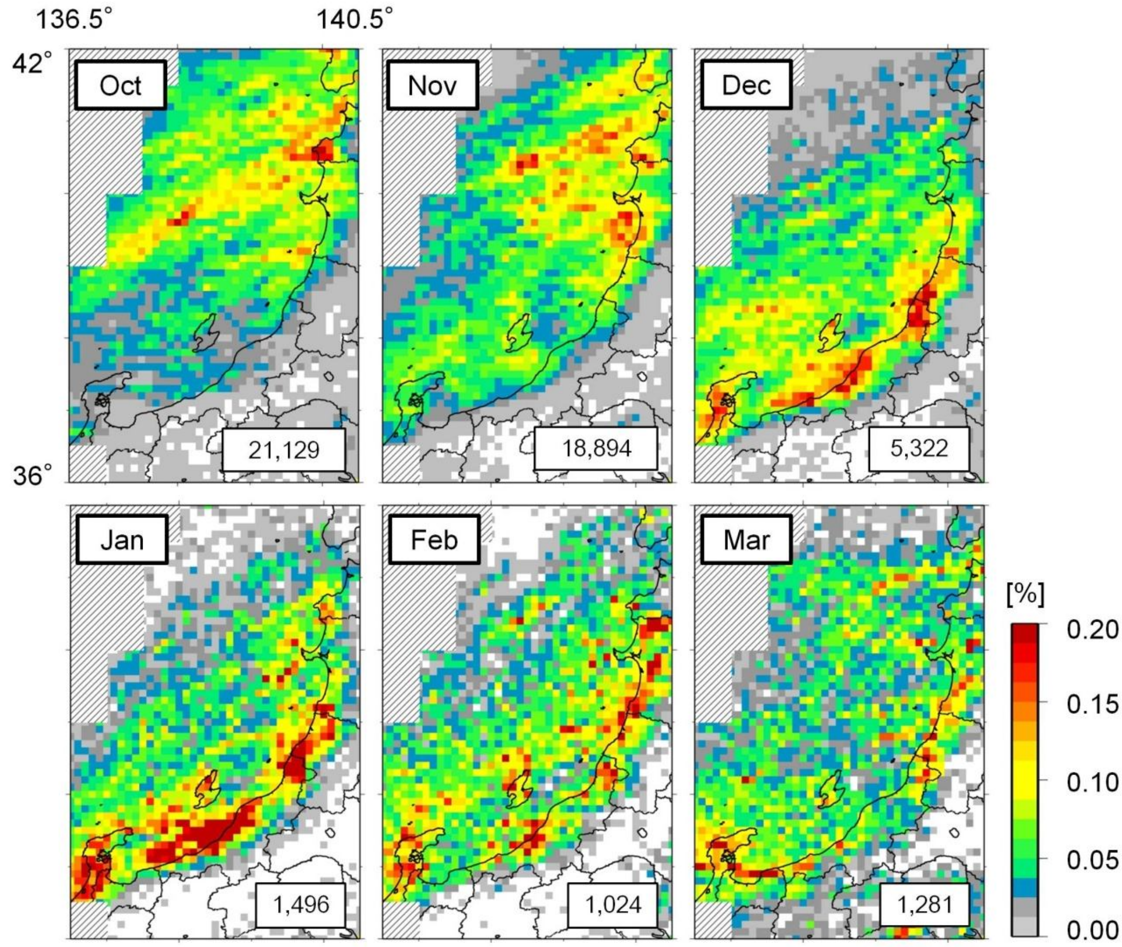

Fig.2 Seasonal variation of lightning frequency distribution in the study area. The maps indicate annual mean lightning frequency of the past 17 years (1994-2010).

3.2. Composite meteorological field on Lightning day

Composite analysis of ERA-interim was carried out in order to examine meteorological conditions required for lightning occurrences in the study area. Fig.3 shows the composite meteorological elements (sea-level pressure, geopotential height and air temperature) on lightning day (defined as daily lightning frequency in the study area exceeding 100[stroke]). The results indicate that lightning activity in the study area is associated with synoptic-scale cyclones passing over the Sea of Japan.

Moreover, the seasonal changes in lightning frequency distribution might be related to changes in surface wind field over the Sea of Japan. Fig.4 shows composite images of lightning frequency, surface wind and horizontal wind divergence on the lighting day. According to Fig.4, the prevailing wind direction over the Sea of Japan was westward or southwestward during late-autumn season, resulting in strong convergence especially in northern part of Tohoku district. During mid-winter season, the winds over the Sea of Japan changed northwardly as the cyclone track moved southward (see Fig.3). This change in wind pattern led to an increased wind convergence in Hokuriku district. During late-winter season, as the northward wind component over the Sea of Japan weakened, the strong convergence zone formed again in Tohoku district. These features are consistent with the seasonality of lighting frequency distribution.

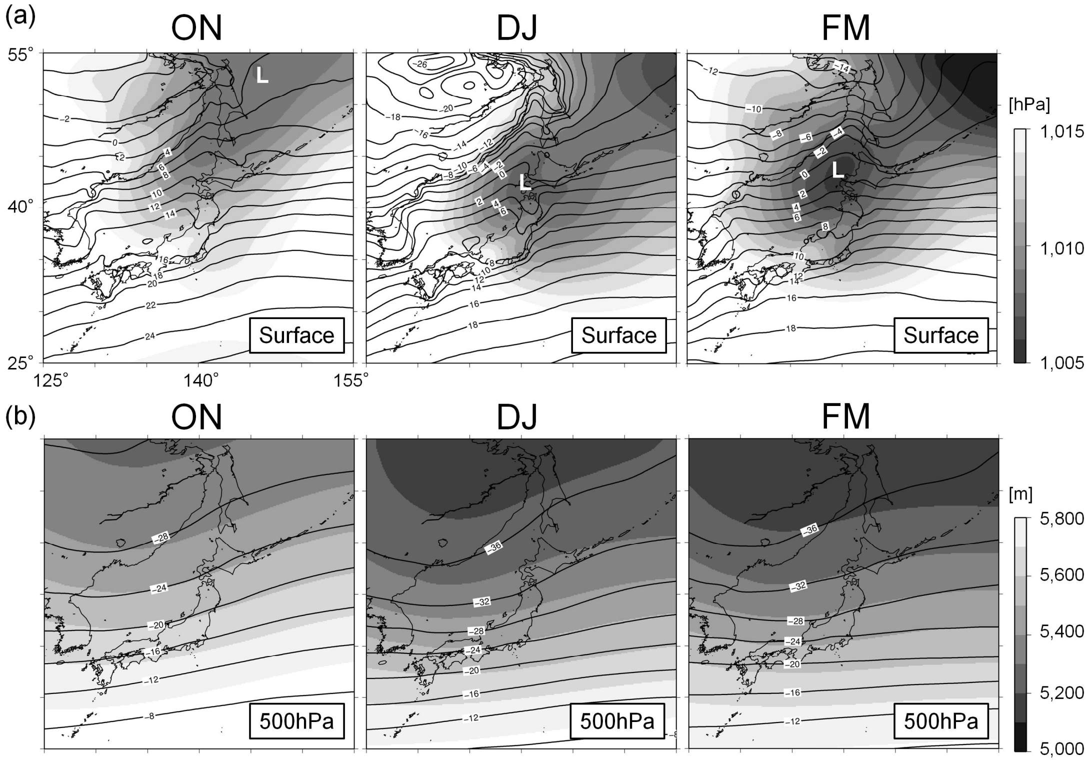

Fig.3 Composite images of meteorological elements on Lightning day. (a) Sea-surface pressure (gray scale) and surface air temperature [deg.C] (contour). (b) Geopotential height (gray scale) and air temperature [deg.C] (contour) at 500hPa pressure level.

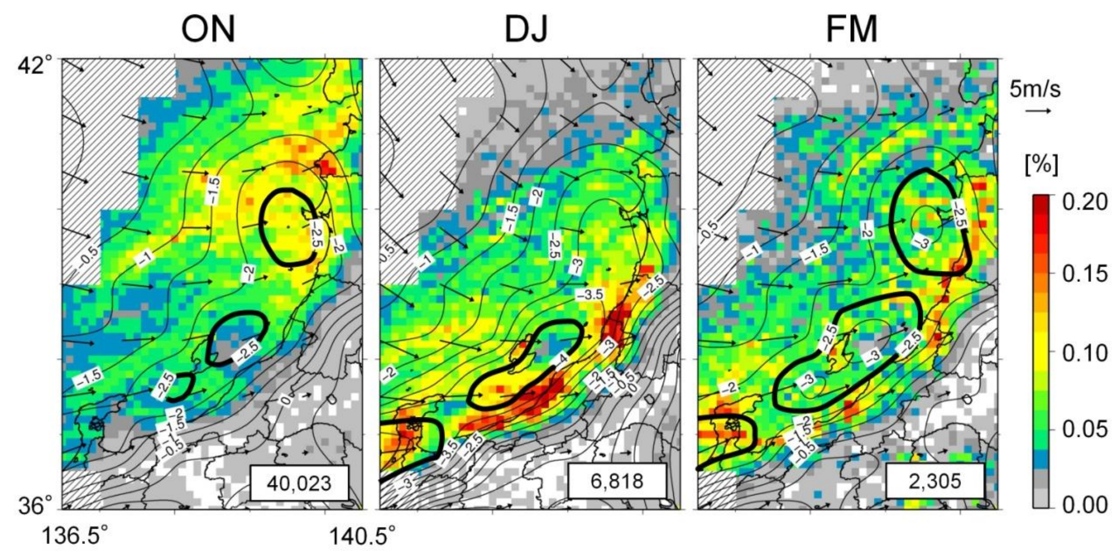

Fig.4 Composite images of lightning frequency (color scale), surface wind (arrows) and horizontal wind divergence [x10^{-5}/s] (contour) on Lightning day. Regions enclosed with bold lines are relatively strong wind convergence zones.

3.3. Results of case studies

In order to examine the physical relationship between lightning activity and meteorological disturbances (e.g. extra-tropical cyclones), detailed case studies were implemented based on MSM-GPV (see section 2.2). For CaseC1, the representative case of late-autumn season, most of the lightning occurred over a cold front associated with cyclone activity (Fig.5). In this case, the lightning frequency was high in ocean areas, as the cold front passed over the Sea of Japan.

For CaseC4-1, typical to mid-winter season, little lightning was observed over cold fronts, since the intensity of the fronts was relatively low. Contrarily, higher lightning frequency was recorded in warm sectors of cyclones and in topographical wind convergence zones, both located close to the shoreline (Fig.6). These findings may explain the mid-winter concentration of lightning near the coastline as documented in section 3.1.

3.4. Scarcity of "Advection lightning"

Finally, the study results indicate a scarcity of "Advection lightning", which previous studies have regarded as the dominant type of winter lightning (e.g. Kitagawa, 1996). This inconsistency could possibly arise from a difference in data processing methods or some regional features of the study area. However, further discussion of such aspects will be explored in future works.

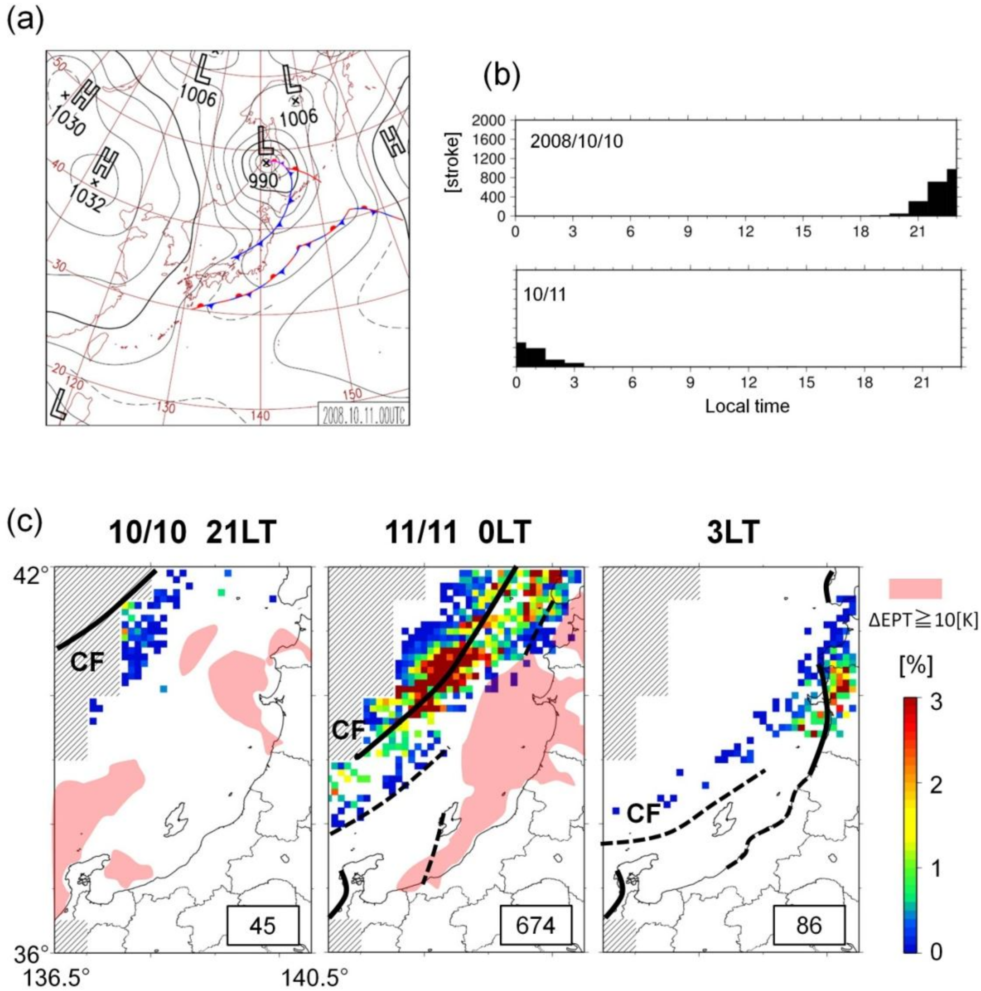

Fig.5 Comparison of meteorological fields and lightning activity of CaseC1 (October 10-11, 2008). (a) Surface weather map on October 11, 2008 (0UT). (b) Time series of lightning frequency in CaseC1. (c) Comparison of lightning frequency distribution (color scale), location of wind convergence lines (solid and broken lines) and high convective instability regions (highlighted in red). Solid and broken lines are equivalent to strength of wind convergence (strong convergence line is expressed as the solid lines). CF in each map show the convergence line associated with the surface cold front.

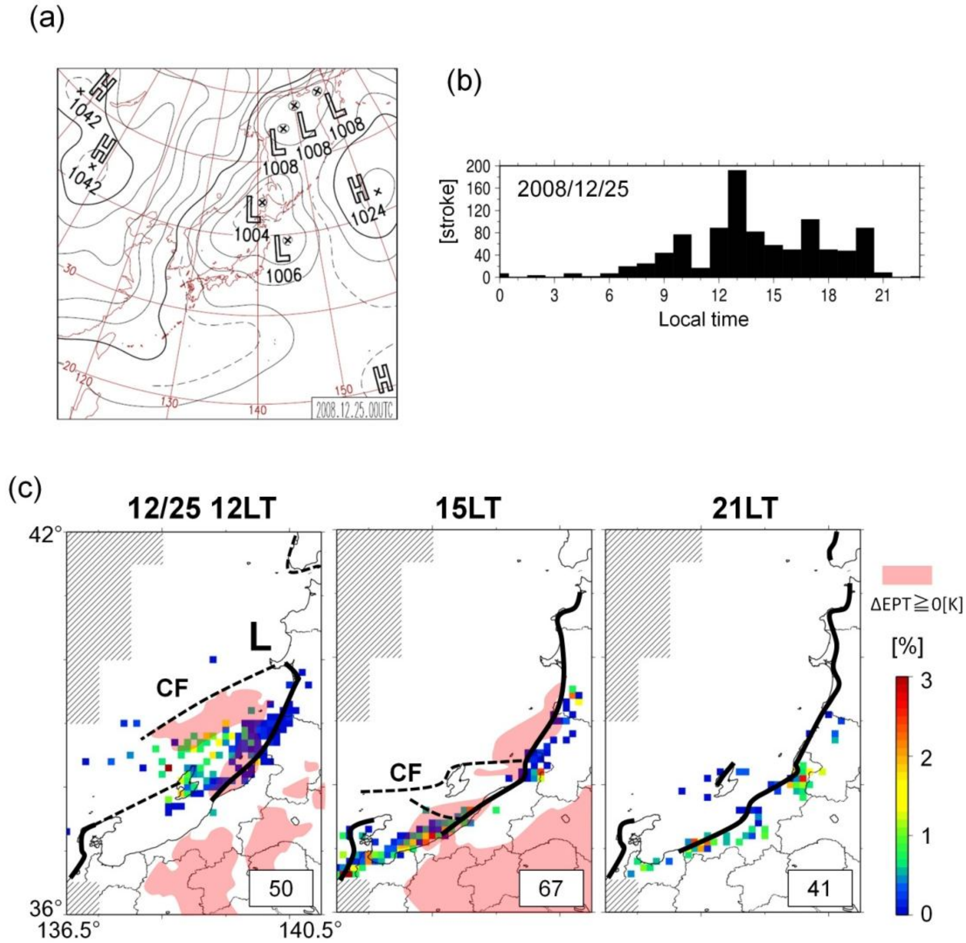

Fig.6 Same as Fig.5 but for CaseC4-1 (December 25, 2008).

References

北川　信一郎(1996)：日本海沿岸の冬季雷雲の気象学的特徴．天気，**43**，89-99.

藤沢　仰・川村隆一(2005)：北陸地方における冬季雷の傾向と落雷発生環境．天気，**52**，449-460.

Brook, M., Nakano, M., Krehbiel, P. and Takeuti, T.(1982)： The electrical structure of Hokuriku winter thunderstorms. Journal of Geophysical Research, **87**, 1207-1215.

Honma, N.(2010): Detection efficiency of the Tohoku IMPACT sensor network in winter. 21st International Lightning Detection Conference.

Honma, N., Suzuki, F., Miyake, Y., Ishii, M. and Hidayat, S.(1998): Propagation effect on field waveforms in relation to time-of-arrival technique in lightning location. Journal of Geophysical Research, **103**, 14141-14145.

Racov, V. A. and Uman, M. A.(2007): Lightning: Physics and Effects. Cambridge University Press.

（別紙）

論文審査結果の要旨及びその担当者

論文提出者氏名	鶴島 大樹
論　文　題　目	東北地方の落雷位置標定システムを用いた寒候期雷活動の時空間構造に関する研究
論文審査担当者	主査　教 授　境田 清隆 准教授　上田 元 准教授　村田 功

論文審査結果の要旨

鶴島大樹提出の論文は，落雷位置標定システムを用いて東北地方の寒候期雷活動の実態と発生要因を解明したものである．日本海から東北地方の日本海側地域は北陸地域と同様に，秋季から冬季にかけて雷活動が活発化し，電力設備等に甚大な被害をもたらしているが，その実態と要因に関しては必ずしも明らかになっていない．

本論文では，東北電力の落雷位置標定システム（LLS）を用いることによって，時間的にも空間的にも極めて詳細な解析を実施した．従来の雷研究においては，地上の気象観測やレーダー観測などに依拠していたため，時間的・空間的解析能力が大きな制約条件となっていたが，電力会社の落雷位置標定データはその制約を解消するものとして注目され，特に東北電力のそれは長期間（17年）に渡って安定的なデータを供給している．

本論文の第３章ではLLSの17年間のデータを用いて，晩秋期（10・11月）から厳冬期（12･1月）にかけて発雷域が秋田沖から北陸沖に南下し，晩冬期（2・3月）に再び北上する季節変化を明らかにした．また発雷頻度は晩秋期に最大となるが，厳冬期では大電流を伴う雷が生活圏に近い海岸線近傍で発生しやすいことを明らかにした．

第４章では再解析データを用いて，寒候期雷の発生要因がほとんど総観規模の低気圧であり，晩秋期では北方低気圧が，厳冬期では日本海及び二つ玉低気圧が主要な要因であることを明らかにした．従来の研究では冬季季節風の寒気移流が主たる要因とされてきたが，それは限られたケースであることを明らかにした．従来の研究が北陸の陸上観測に依拠していたためであり，東北地方西方の日本海上の発雷要因を正確に捉えた解析結果といえる．

第５章では，クラスター分析によって時空間構造をタイプ分類した上で，抽出された典型例に対して，さらに詳細な再解析データを用いて事例解析を試み，晩秋期では前線付近の収束が，厳冬期では暖域内の対流不安定が重要であることを明らかにした．また厳冬期の発雷では地形収束も重要な役割を担っていることを明らかにした．

上記のように，本論文は，LLSを利用して日本海上を含む広範な領域において長期の発雷データを解析した結果，東北地方西方と北陸地方間で季節移動していること，さらに詳細な気象場の解析から，前者が寒冷前線に沿って発生するのに対して，後者は暖域内の不安定と地形収束が主たる要因となっているなど，多様な時空間構造において新たな興味深い多数の知見が得られた．これらの知見は，寒候期雷の予測を通して，今後注目されるであろう寒候季雷被害の軽減において，重要な研究と高く評価できる．

このことは著者が自立して研究活動を行うに必要な高度な研究能力と学識を有することを示している．よって，本論文は，博士（環境科学）の学位論文として合格と認める．